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GIANT COMETS, EVOLUTION AND CIVILIZATION

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Climatic cycles, ice epochs, mass extinctions and other global disturbances may be attributed to episodes of bombardment by giant comets. Such bodies now in chaotic orbits beyond Jupiter present the most serious current celestial hazard.

Evidence for the periodic incidence of large–scale terrestrial phenomena [1] has grown substantially during the past 70 years. The periodic value ~26 million years, moreover, is strikingly close to the interval between successive Solar System crossings of the Galactic plane [2], a fact which suggests that there might exist a predictable celestial mechanism which exerts a control over such fundamental processes as the evolution of life. In spite of its scientific and human importance [3], however, it is only during the last quarter of the present century that the physical aspects of the galacto–terrestrial relationship have ceased to be enigmatic.

Thus, whereas until the mid–1970's, the Oort cloud was generally thought of as a stable, primordial system essentially not influenced by its Galactic environment, it now appears that sequences of giant comets perturbed into Earth–crossing orbits by periodically varying tidal forces of Galactic origin are the probable key to terrestrial evolutionary processes [4]. It turns out, for example, that the ~26 Myr period of the late Phanerozoic pulsation (*i.e.* since about 260 million years BP) is indicative of the Galaxy's longer

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term influence on the Oort cloud while the current (Pleistocene/Holocene) ice epoch and its ~0.1 Myr alternation between glaciation and greenhouse are broadly indicative of a current more localized Galactic influence close to the plane [5, 13]. The current arrival rate of giant comets implies that they are a prime celestial hazard to civilization; thus it appears that the last (*i.e.* latest Pleistocene) glacial and its aftermath, the current (Holocene) interglacial, may be associated with the disintegration and decline of the single, most recent, giant comet in near–Earth space [6]. This has led to a very natural focus now on the lesser but still significant hazards due to the still disintegrating debris of this giant comet, producing dark– and mini–ice ages on millennial and centennial timescales respectively [3]. The near–Earth arrival frequency of giant comets, $\sim 10^{-5}$ per annum, is much the same as that of ~1–kilometer asteroid impacts, but the adverse environmental effects of giant comets, although comparable in severity, are much more prolonged. In the present study we consider the giant comet issue from both astrophysical and climatic perspectives. A point at issue is the greater complexity of the cometary as opposed to the asteroidal hazard, as well as its more pervasive effects.

Periodic Extinctions and External Forcing

The coincidences in age between tektites and Tertiary extinction events were an early indication that extinctions and cometary impacts could well be related [7]. An extinction mechanism then proposed was the attenuation of sunlight through stratospheric dust injection from the meteor stream of a large comet, not least for the Cretaceous–Tertiary event [8, 40]. Furthermore, it did seem that both impact cratering and global tectonic events could be understood in terms of bombardment episodes every ~26 million years [9]. The specific Galactic connection only emerged however with the realization that global terrestrial disturbances associated with bombardment episodes could be both regular (periodic) and random on appropriate timescales provided large comets were correspondingly dislodged from the Oort cloud as the Solar System moved through the Galaxy. Conceived as a general theory of catastrophic evolution, this meant that major extinctions such as the KT event were probably due to ~10–kilometer (cometary) asteroids [10, 5]. Thus the implied galacto–terrestrial relationship was based on prior astrophysical

considerations and was by no means purely a response to the discovery of iridium anomalies [11] or other extraterrestrial markers at the KT boundary.

Appropriate geological databases have now improved to the point where the periodicity claims can be subjected to quantitative analysis and accurately assessed. Thus in a 1992 compilation [12] of databases of the past ~260 Myr, seventy six well–dated major geological events were catalogued comprising 11 mass extinction peaks, 13 ocean anoxic and black shale events, 12 continental flood basalt vulcanisms, 9 large discontinuities in sea–floor spreading rates, 17 dates of widespread stratigraphic sequence boundaries (usually indicating major periods of low sea level) and 14 mountain building events. Power spectrum analysis of these data yields evidence of an overall ~26 Myr periodicity coupled with a recent out–of–phase surge [12, 13]. The latter commenced some 5 Myr BP, merging with the onset of the Pleistocene glaciations about 2.5 million years ago.

In Table I the 'best fit' periodicity for all the data combined is compared with the individual mass extinction peaks from the compilation, and with the periodicity for all the other geological phenomena (*cf.* Fig. 1). In constructing the peaks the recent significant surge of activity (in the Pleistocene) has been excluded. Clearly the mass extinctions, and the other major geological events, fit closely to the same ~26 Myr periodicity, separately and together. The amplitude of the periodicity is large, the whole Earth switching on and off in a regular cycle. The period and phase are remarkably stable against progressive truncation of the dataset (Fig. 2).

The existence of a periodicity in the major episodes of geological activity strongly constrains the possible forcing mechanisms. The end–Cretaceous extinctions (~63 Myr), the Deccan Trap outpourings (~65 Myr BP) and the Chicxulub impact crater (65.0±0.2 Myr) are closely coincidental in time, but also fit on to the 64 Myr BP peak of the 'Holmes cycle'. Unless these coincidences are due to chance, it appears that the periodicity cannot be explained by endogenous forcing, say arising from mantle convection processes. Likewise the impact of stray bodies from the asteroid or Kuiper belts seems not to be primarily involved – notwithstanding the Spaceguard project [14] – since these belts are not, so far as is known, subject to disturbances with this periodicity. A further constraint arises from the fact that the dynamical lifetime of an object in a near–Earth orbit is about 30 million years, adequate to smear out any periodicity in their arrival rate unless the perturbing Earth–crossers are physically short–lived. Rocky or iron asteroids are therefore excluded as prime movers, consistently also with the absence of bulk

meteoritic material at the KT and other extinction boundaries.

Extraterrestrial ^{3}He of probable cometary origin has recently been detected in a North Pacific pelagic clay core dating back over 70 Myr [15]. The implied flux of cometary dust is highly variable, showing strong peaks at $\sim$66 Myr, $\sim$37 Myr and $\lesssim 2$ Myr BP (*cf* Table I). There is thus direct evidence for an association between comet dusting and geologically noisy epochs. At higher resolution, the dust deposition correlates strongly with a 0.1 Myr cycle in the climatic record of the past million years [15]. The latter seems to imply a likely enhanced capture probability of comets as the ecliptic crosses mid-latitude Galactic bands [19] and where comets have perihelion and nodal precession rates (g, f) which match the 'grand cycles' close to simple multiples k_j (j=5,6,7,8) of the major planetary secular resonances (g_j, s_j) [16], *eg* when $|g|, |f| \simeq 3.25$ arcsec/yr.

Galactic Encounters and the Pleistocene Surge

Such constraints and the longer term periodicity are however in quantitative agreement with the perturbation function applied to the long–period comet system, or Oort cloud. This comprises some 10^{11} objects which orbit the Sun at distances of up to 60 000 astronomical units and remain only just gravitationally bound to it. It is through the action of an externally induced tide (or differential gravitational field with respect to the Sun) that a flux of comets into the planetary system is maintained [17]. That part of the flux which is deflected rapidly and terminally into sub–Jovian space, *i.e.* through Jupiter–family and Halley–type orbits [4], becomes the most likely to interact with the Earth. It follows that the comet–Earth interaction varies overall in direct proportion to the ambient differential field affecting highly elongated, Oort cloud orbits. Such tides arise in general through Oort cloud–cum–Solar System encounters with the other relatively moving elements of the Galactic environment; they comprise both steady and impulsive components and so produce both periodic and random surges in the giant comet flux (Fig. 3). Depending on the assumed scale height of dark matter in the Galactic disc, the periodic modulations may easily attain amplitudes of 3:1 or more. Consistency with the observed Holmes cycle is obtained if the half–period of the solar vertical oscillation is $\sim$26 million years. This corresponds to an in–plane density $\rho_z \simeq 0.18\, M_\odot\, pc^{-3}$ for the ambient Galactic disc [18], im-

plying the presence of dark matter in the disc with an extreme Population I distribution.

The long–period comet aphelia currently possess an underlying isotropic distribution deficient in objects close to the Galactic poles and equator, broadly in accordance with the Galactic tide [19] complemented by individual (stellar and dark matter) perturbers. In addition, however, there is an excess of cometary aphelia around the Solar antapex direction spread along a 90^o segment of the great circle which includes the Galactic centre [20]. This accords very well with the current Solar vector and the observed location of the nearest large mass in the Galactic environment, namely Gould's Belt (Fig. 4). The latter appears to be a disintegrating molecular cloud of one or two million solar masses, which the Solar System began to encounter 10 ± 2 million years ago. Allowing for the infall time (~3–4 million years) of disturbed long–period comets, passage of the Solar System through the Belt may be associated with the recent Pliocene surge, which began ~5 Myr BP and includes three orogenic events, two sea floor spreading discontinuities, five evaporite depositions and a mass extinction ~1.5 Myr BP merging with the onset of the current ice epoch [13].

Comet Splitting and Stratospheric Dust

The observed inverse semi–major axis (*i.e.* orbital energy) distributions of long– and short–period comets have long been understood in terms of strong planetary encounters in association with hierarchical splitting (*cf.* Comet P/Shoemaker–Levy 9), the fragments being increasingly faded and resilient [21], as would be expected, for example, were the largest representatives (diameters $\gtrsim 100$ kilometers, say) to have carbonaceous chondritic cores just as the larger parent bodies of meteorites (diameters $\gtrsim 500$ km, say) are expected to have more purely chondritic cores. Thus, to the extent that the long–period comets are also the source of short–period ones, classified as Jupiter–family or Halley–type [22], it is natural that these derivatives should continue to split and are represented as a whole by populations in excess of the expected unsplit dynamical transfers which include large devolatilized members such as Chiron. Splitting is a commonly observed process: 21 comets have been recorded as doing so between 1846 and 1976 and three since 1989 [23]. It occurs at a rate of one or more events per

comet per century and is a likely major mode of disintegration and evolution. The precise mechanism is not known except for those comets which pass within the Roche limit of a planet or the Sun; and the emergence of differing constitutional types among remnants on the occasions of these rare events seems to indicate compositions which are heterogeneous on all scales, including some which cannot withstand typical tidal or explosive forces. It is likely that short–period comets make close passages to Jupiter every century or so and if one in a thousand of these is a giant comet (diameter $\gtrsim 100$ kilometers), splitting into thousands of fragments, then major upsurges in the Jupiter–family population will take place within its dynamical lifetime, thereby accounting for an observed excess in this population [24]. A more extended disintegration pattern can be expected for the giant comets deflected into sub–Jovian space as they will tend to experience close encounters with terrestrial planets. For example sub–Jovian space currently contains a single broad complex of (cometary) asteroidal and meteoroidal debris known as the Taurids, with a dynamical lifetime of $\sim 10^{-2}\, Myr$ [6].

In general, visible comets grow tails, losing dust and volatiles, when their orbits acquire perihelia of $q \lesssim 2.5$ AU, and many are associated with meteor streams observed when the Earth intersects their orbital tracks. The active comets are clearly evanescent bodies, with lifetimes one to ten millennia, and so represent the tip of an iceberg, with a large undiscovered population of inert bodies belonging to the Jupiter and Halley families. The mass distribution of comets is a power law with index $\sim$–1.7, possibly steepening to $\sim$–2 at the high mass end. The cumulative flux of large long–period comets is given by $F \sim 1 \times (d/5)^{-2}$ comets $\mathrm{AU}^{-1}\, yr^{-1}$, d the diameter of the comet in kilometers [4]. There is no securely known upper limit to d, but several historical comets, such as the Great Comet of 1577 and Comet Sarabat of 1729, appear to have had diameters in the range 100–300 km and masses $\sim 10^{21} - 10^{23}\, g$. Chiron, in a chaotic orbit which currently lies beyond Saturn, may be 180 ± 30 km in diameter. A giant long–period comet ($d \gtrsim 100$ km) is therefore expected to cross the Earth's orbit about once every 400 yr, a Sarabat–sized body ($\gtrsim 300$ km) once within the timescale of civilization. The injection rate of giant comets from a chaotic, trans–Saturnian orbit into a *stable* Earth–crossing one is of order 10 Myr^{-1}.

A comet with $d = 200$ km and mass $M = 10^{23}\, g$ thrown into a Taurid–like orbit P($\sim$3.3 yr, eccentricity $\sim$0.85) will lose $\dot{M} \sim 10^{18}\, g\, yr^{-1}$ due to outgassing, more than half of it as meteoroidal dust with diameters in the range $0.01\, \mu$m to several mm [25]. A particle size distribution $n(a)da \propto a^{-3.6}\, da$,

$a \geq 0.01\,\mathrm{mm}$, is indicated by the Halley data, implying a significant pile-up of mass in the submicron size range. Outgassing and dust production will not be uniform with time: the overall active lifetime of the comet ~3000 yr may be interspersed with dormant periods when the surfaces become temporarily crusted. During its active lifetime such a comet could generate a zodiacal cloud of mass ~300 times that of the present one.

Solar radiation pressure forces have an important role in separating the various grain sizes and compositions within the cloud. The critical ratio of radiation pressure force to gravity below which particles will be retained in bound orbits depends on the eccentricity of the parent cometary orbit as well as the precise point on the orbit at which the particles are released. For a comet in a circular (or near circular) orbit with radius 1 AU, the condition for retention is $P/G < 0.5$; for a comet in an elliptical orbit with $e = 0.7$ (a Jupiter comet) the appropriate condition is $P/G < 0.85$ for aphelion emission, and $P/G < 0.15$ for perihelion emission [39]. These conditions are marked by the dotted and dashed lines in Fig. 5. The several curves show the ratio P/G from Mie-type computations for spherical particles of graphite, iron and dielectric compositions (minerals or organics). We consider dielectric grains with varying degrees of porosity, D_{100}, D_{60}, D_{40} referring to non-porous, 60% volume-filled and 40% volume-filled respectively. The dielectric material in these calculations is taken to have a bulk refractive index $m = 1.5$ and density $2\,g\,cm^{-3}$. Whilst sub-micron iron and graphite (metallic) grains are seen to be easily lost according to our computed P/G criteria, organic or mineral grains of all sizes which are <60% volume-filled would be wholly or mostly retained in bound orbits, depending upon the point in the orbit at which they are released.

For dust particles in bound orbits the main loss mechanism from the zodiacal cloud would be due to Poynting-Robertson drag forces. The Poynting-Robertson timescale at 1 AU is plotted in Fig. 6 for each of the grain types considered. We note that iron grains of radii $0.1\,\mu$m and organic/mineral grains of radii $0.03\,\mu$m have Poynting-Robertson timescales of 3000 yr on the average, whereas graphite particles have considerably shorter lifetimes. The longest Poynting-Robertson timescale is calculated for porous dielectric grains, with $t \geq 10^4$ yr. A zodiacal cloud resulting from a cometary evaporation episode would thus have an average lifetime of $\sim 10^4$ yr.

Modelling this temporary zodiacal cloud as a disc of mass 5×10^{21} g, radius 1 AU and thickness 0.2 AU, it is found that $\sim$ 10^9 tons of dust are swept up by the Earth annually over a few millennia when the comet

is active. A porous mineral/organic IDP particle of radius 0.1 - 0.3 μm and density 1 $g\,cm^{-3}$ has a settling time through the atmosphere of about 3–10 yr and such grains are efficient scatterers in the optical wavelength range. It is readily estimated that the Earth gathers up a stratospheric dust veil whose optical depth may fluctuate in the range $0.05 \lesssim \tau \lesssim 3$ during the cometary active lifetime of 10^3–10^4 yr.

For a mixture of micron and submicron grains incident on the Earth's upper atmosphere, the submicron component would tend to be optically dominant. The mean scattering angle of a $0.1\mu m$ particle is $\sim 90°$ [?], almost independently of composition, and its settling time through the stratosphere is about a decade [26]. Because the settling time of μm grains is about 1 year, it follows that if equal masses of μm and 0.1 μm grains are incident on the upper atmosphere, the smaller sizes will accumulate in the stratosphere relative to the larger ones. Further, very fragile sub–cometary meteoroids of $\sim$metre dimensions may disintegrate to $\sim 0.1\,\mu m$ particles during their pre–atmospheric descent [27], and may compete with the preformed zodiacal dust as a major source of optical depth. One thus expects that, in the presence of a disintegrating giant comet, the Earth will be enveloped in a highly reflective dust cloud.

Glaciation and Greenhouse

Without the greenhouse effect the Earth's mean temperature, averaged over latitude, day and night, and land and sea, is given by $[F_\odot(1-A)/ac]^{1/4}$, where $F_\odot = 1.37 \times 10^{-6}\, erg\, cm^{-2}\, s^{-1}$ represents the solar energy flux at the Earth's distance from the Sun. Here A is an averaged value for the Earth's albedo, c is the speed of light and $a = 7.565 \times 10^{-15}\, erg\, cm^{-3}\, deg^{-4}$ is the radiation density constant. Thus for an albedo of 0.4 the Earth would have a mean temperature $\sim$245 K or -28 C. Opacity sources are highly wavelength dependent, and we seek an approximation with the virtue of physical rectitude rather than attempt to set up a supposedly accurate computation in which approximations of uncertain physical validity are nevertheless made in the end! Thus if we divide the re–radiated energy at ground and sea level into two essentially equal halves about a central wavelength at $\lambda = 13.5\mu m$ (say), then we may suppose that half the emission, longward of 13.5 μm, is completely blocked by the heavy opacity of greenhouse gases while the re-

mainder, shortward of 13.5 μm, is completely free to escape. It follows that the greenhouse effect raises the Earth's mean temperature by a factor of $2^{1/4}$, *i.e.* to about 292 K (19 C) rather than 245 K, a result agreeing closely with experience.

In practice, water vapour and CO_2 are the main greenhouse gases. The CO_2 produces essentially the whole of its effect through absorption in the infrared over 13.5μm to 17.5μm. Because the blocking by carbon dioxide over this interval is large, the band having steeply–falling wings, additions of CO_2 have only a second–order influence on the greenhouse effect and are inconsequential compared to the major factor, water vapour, controlling the Earth's climate. There is weak absorption by water vapour shortward of $\lambda = 13.5\ \mu m$ while its blocking effect rises all the way from 17.5 to $\sim 100 \mu m$. In other words, there is a partial window at $17.5 \lesssim \lambda \lesssim 20\ \mu m$ which roughly compensates the blocking shortward of $\lambda = 13.5 \mu m$, essentially justifying the adopted approximation. Evidently then, it is water vapour, that of a 'standard atmosphere' implying 1 cm cm^{-2} of precipitable water, which raises the Earth's temperature by $\sim$40 C and without it, the Earth would now be locked in a permanent ice age [28].

Reducing the water content of the atmosphere to a few mm cm^{-2} weakens the greenhouse, dropping the Earth's mean temperature (for the same A) to $\sim$280 K, which corresponds closely to what is required for typical ice age conditions. It follows that a reduction of the average water content by about two thirds, while maintaining the albedo, would produce an ice age. The same result would be achieved if A increased from 0.4 to 0.5 or if the insolation of the upper atmosphere declined by about 16 percent. Such albedo and insolation are readily attained when the Earth intersects material in orbit associated with the disintegration of a giant, active comet. Very large comets, it appears, will trigger the onset of glaciations.

Ice–age conditions have generally been dry and cold. The great deposits of loess (wind–blown soil) in Eastern Europe and China imply a climate that was dusty in the lower atmosphere, implying a low precipitation rate. Low precipitation is not a handicap in the accumulation of large glaciers, which will grow even at annual precipitation rates as little as a few cm/yr, provided that the temperature is low enough to prevent summer melting.

During the ice ages the whole Earth was cooled, including the tropics. This is proved by glaciers extending down to about 10,000 feet on tropical mountains which do not at present hold glaciers, such as those on Hawaii. The need for the whole Earth to be appreciably cooled is difficult to rec-

oncile with ice–age theories depending solely on small oscillations of the Earth's rotation axis relative to the ecliptic plane, and small oscillations in the Earth's orbital eccentricity. Neither of these effects produces any change in the amount of solar energy incident on the Earth and so could not lead to widespread cooling. Oscillations of tilt merely produce slight latitudinal variations in the incidence of solar energy, which are in any case much smaller than the transport in latitude of heat by atmospheric storms and ocean currents. The transport of oceanic heat towards the poles gives a far larger effect and would easily buffer slight latitude variations of insolation. Oscillations in eccentricity of the Earth's orbit produce small shifts of solar energy between one geographical hemisphere and the other, and so should tend to cool one hemisphere and warm the other. But ice–ages occur contemporaneously in both hemispheres, not alternately, a disproof that was already understood more than half a century ago. The presence of the Milankovitch cycles is currently controversial: the most accurate climatic chronology covering the last 500,000 yr, obtained from calcite deposits in the Devil's Hole fissure in Nevada, appears to indicate a chaotic behaviour for the climate over this period [29]. However the marine pelagic record appears to support the 100,000–year cycle [15]; this may be due to a combination of planetary resonances resulting in periodic giant comet dusting.

If we were to imagine a cold, dry atmospheric state being brought about today, evaporation from the relatively warm surface layers of the ocean would quickly resupply water vapour to an amount of 1 cm of precipitable water per cm^2, and the cooling due to a reduced greenhouse effect would quickly be gone. Thus it is the heat of the ocean which saves us from the possibility of an immediate onset of ice–age conditions. Reckoning the heat of the ocean as being the energy content above freezing point, which can be thought of as available heat, almost all is contained in a surface layer with depth no greater than a few hundred metres, the amount being equivalent to a supply of sunlight over a time interval of a few years, say 3 to 5 years. It is because the ocean has this back storage of heat that we do not drop almost immediately into an ice age.

In distant geological periods the heat storage in the ocean was considerably greater than it is at present. Today the ocean waters are close to freezing, whereas only 50 million years ago the bottom temperature was $\sim 15^{o}C$ and the available oceanic heat was then equivalent to a 50 year supply of sunlight. The difference has been attributed to drifting continents, especially by the positioning of Antarctica and Greenland at or close to the

poles. Melt water from Arctic glaciers has gradually filled the lower ocean with water close to freezing, greatly reducing the margin of safety against ice–age conditions developing. The past two million years have essentially been a continuing ice–age therefore, broken occasionally by short–lived interglacials. But clearly, from this perspective, the prospect of a drift away from an ice age, through an enhanced greenhouse effect, may be of less concern than that of a drift back into an ice age. Thus we need sustain the insolation at a significantly lower value than at present *for only several years* to lock enough water vapour into ice to create the permanently cold, dry atmospheric conditions of an ice age.

Changes in the Earth's albedo

A remarkable feature of the Earth's albedo is that it may very easily be raised to values close to unity. The mass extinction coefficient, through the scattering back into space of sunlight, produced by dielectric crystals with radii of a few tenths of a micrometer, is $\sim 3000\, cm^2\, g^{-1}$ (backscattering amounts to about 10% of the total scattering [40]).Such an albedo change would arise, for example, if even a very small fraction of even a very dry atmosphere were to condense into ice crystals. Thus a crystallization of only 0.1 percent of the water in a very dry atmosphere (say with only 1 mm of precipitable water) would yet contribute about 0.3 to A. Essentially no water must be condensed into ice crystals if A is to be appreciably less than unity; otherwise the Earth would appear from the outside as an intensely bright white planet with an albedo even higher than that of Venus, while below the haze of ice crystals it would be exceedingly cold at ground level. The same result would arise from the injection of $\sim 10^{14}\, g$ of $\sim 0.1 \mu m$ dielectric particles to the upper atmosphere. This might easily happen if the zodiacal cloud were to be flooded with the debris of an exceptionally large, disintegrating comet in a short–period orbit, or if asteroidal debris from such a comet were to strike the Earth. We discuss here the ice and dust mechanisms in turn.

The saving grace in the case of ice crystals is that they do not form in supersaturated water vapour except at very low temperatures, say –50 C [30]. For the Earth's emission into space of radiation at wavelengths longer than λ=20 μm we can think of a photosphere at which the optical depth out into space is of order unity. If only radiation were involved in determining the

water vapour temperature at this photosphere the temperature would be of order $290\tau^{-1/4}$, where τ was the optical depth from ground level up to the photosphere, suitably averaged at wavelengths $\gtrsim 20\,\mu m$. In a typical atmosphere τ would be about 10, leading to a photospheric temperature for water vapour (and hence for surrounding air) of as little as 163 K, *i.e.* –110 C, far below that needed for ice crystal formation. The circumstance that ice crystals do not form profusely except under special circumstances in Antarctica shows that calculating for radiation alone cannot be correct. A convective transport of energy from ground–level to the water–vapour photosphere is required. This cannot be carried by air movements but must come from the upward transport of the water vapour itself. To keep the photospheric water vapour temperature above –50 C, and so to prevent ice crystal formation, the transport of water vapour must be such as would lead to an annual precipitation rate of about 50 cm [30]. For comparison, the present–day worldwide average of the precipitation rate is about 80 cm of rain, sufficient to prevent ice crystal formation, but not by a wide margin. Let the world climate decline, however, sufficiently for the surface layers of the ocean to cool to the point where an annual average rainfall of 50 cm cannot be maintained, and the consequent formation of an atmospheric haze of ice crystals would plunge the Earth immediately back into an ice–age. Such sensitivity of the Earth's albedo due to ice crystallization would appear to indicate an additional tendency on the part of the atmosphere–ocean circulation to produce rapid ice age conditions in the presence of externally injected dust [31].

The KT Event Revisited

Amongst the effects which were predicted [32] as a consequence of giant comet incursions into short–period, Earth–crossing orbits were multiple impacts, high concentrations of extraterrestrial material, prolonged climatic deterioration, ocean regressions and a complex depositional history. These effects are over and above the prompt effects associated with large impacts, and permit a discrimination between the stray impact and cometary hypotheses. Since the KT boundary has been intensively studied for the past decade, it provides a good test between them. Thus amino acids of probable extraterrestrial origin appear to have been laid down over a ~0.1 Myr period around the boundary. Any such molecules would have been destroyed in the $\sim 10^5$K fireball [33, 34]. The data, however, are consistent with a

protracted input of extraterrestrial organics in the form of submicron-sized IDPs. Another observation suggesting a prolonged period of dust input is that the probable extraterrestrial component of minerals at several impact sites appears to be one or two powers of ten too high to be consistent with the dilution factor $\sim 10^3$ expected for impacts (*e.g.* ~100% for a basal layer of clay at Woodside Creek, New Zealand: ref. [35]). Likewise the mass of iridium deposited worldwide is overabundant by a similar factor in relation to the probable size of the Chicxulub impactor [36].

As we have already seen, porous submicron grains ($a \sim 0.1\mu$m) of either mineral or organic composition expelled from comets are mostly retained in bound orbits and have Poynting-Robertson lifetimes of ~0.1 Myr at an orbital radius of ~1 AU. Such particles injected into the zodiacal cloud will be accreted by the Earth over the timescale as witnessed in the distribution of extraterrestrial amino acids (AIB). On the other hand, iridium-bearing graphite/metallic grains of sizes $0.01\,\mu$m (appropriate for supernova condensates) will be expelled from the inner solar system on a much shorter timescale. On this basis it is possible to understand why the iridium peak at the K/T boundary clays is considerably sharper than the 0.1 Myr-wide profile of the extraterrestrial amino acids [37].

A shroud of reflective dust accumulated by the Earth and maintained for some 0.1 Myr would lead to oscillations of climate and environmental stresses causing an extended episode of extinctions of species. Such a picture is consistent with terrestrial mean annual temperatures estimated from studies of fossilised leaves. There is an indication of a fourfold rise in precipitation and 10^o increase in temperature for a period of 0.5–1 Myr around the K/T boundary [41]. A wide range of geological and paleontological data seems to require the combination of a fairly sharp extinction spurt centred at 65 Myr as well as a more extended episode of stepwise extinctions. For dinosaurs, however, a consensus is emerging that there was no gradual decline in diversity of genera towards the end of the Cretaceous, but rather a sudden extinction consistent with a concentrated cluster of bolide impacts [42]. On the other hand, groups such as the rudists and inoceradists (bivalves) seem to have disappeared ~1 Myr before the mass extinctions on land. Similarly, Cretaceous foraminifera and dynocysts in K/T boundary clays start disappearing well before the Ir enhancement begins [43]. Depositional and palynological evidence of a double impact layer in the western USA has been presented by a number of workers [38]. The intervals given vary from a few months to ~100 yr, which are several orders less than those expected for a comet

shower, but readily expected from a dense swarm of cometary debris within the debris stream of a short-period, Earth-crossing orbit. Multiple bolide strikes are also indicated by the extensive distribution of soot and products of resinous combustion found in the K/T boundary clay layer [44, 45]. The evidence that a quarter of the entire biomass was combusted is inconsistent with a single impact, but favours the idea of multiple bolide impacts leading to extensive forest fires.

Effects on Civilization and Culture

During the last twenty years or so, there has grown up the idea that random impacts due to stray asteroids are the dominant external influence on evolution [11]. However if, rather, such dramatic events as mass extinctions of species and global climatic catastrophes are attributed to swathes of cometary debris à la Shoemaker-Levy, it would be naive to gloss over the possible implications of the same process in relation to human culture. The Tunguska event of 1908 seems most likely to have been caused by a bolide of $\sim$100 m diameter exploding at a height of some 8 km. The resulting blast wave felled trees over a distance of 40 km, charring them for up to 15 km from the centre of impact. Estimates of a 300–100 year timescale for successive Tunguska-type collisions are based on lunar cratering data [46]; this calculated rate has already triggered interest in projects such as *Spaceguard*. However the lunar maria are $\sim$3.9 Gyr old, and there is no obvious reason why the contemporary impact rate should bear much relation to that averaged over this long time interval. Recent satellite observations of the Earth between 1975 and 1992 have revealed that some 136 sub-Tunguska bolides impacted the Earth's upper atmosphere during this interval, yielding a rate of a few per annum for objects 10–30 m in diameter. For 100 m sized Tunguska-like bolides the current impact rate could well be one in 30–100 years [47, 34].

One Tunguska-like strike per century, despite its attendant horrors, would have little sociological impact. But if in times past similar strikes occurred at the rate of several tens per annum the effect upon our social systems would unquestionably have been profound. Such collisions are possible if the Earth intercepts a debris stream from a disintegrated giant comet, as we have seen. A wealth of historical data exists [34, 3] to support the hypothesis

that fragmentation of a particular comet began some 20,000 years ago and the interception of its fragments on a periodic basis has led to events that moulded our religions, mythology, beliefs and history. The beginning of the present interglacial period is marked by a very sharp rise in temperature at ~13,000 BP, followed by cooling, and a further sharp rise at ~10,500 BP which is subsequently maintained. If this cooling event was occasioned by an intense spurt of cometary bolide impacts due to fragments of a giant comet in Earth-crossing orbits, similar collision episodes with declining intensity may have continued repeatedly throughout history. One could regard otherwise enigmatic events in history such as the sudden collapse of the Indus Valley Civilization of Mohendojaro and of the Old Kingdom in Egypt (accompanied by the most puzzling phenomenon of Pyramid building), both occurring at ~2500 BC, as fitting well with precession of the primary orbital nodes, the countdown to intersection *ca* $500 \pm 2500n$ AD, n=0,1,2... [3] and the (Taurid) cometary collision picture in general. Such intersections accompanied by widespread global cooling are predictably complemented by extended periods of global warming *ca* $1750 \pm 2500n$ AD apparently characterised now by the recorded ice-rafting of oceanic sedimentary debris at these epochs throughout the Holocene [49]. The oldest celestial myths, which involve battles for supremacy between gods in the sky, may date from the third millennium BC although they survived at least through to Homer and Hesiod ~800 BC [34]. The next episode of violent collisions at ~1000 BC may well have generated Old Testament accounts such as the destruction of Jericho. On this basis the most recent episode of severe Tunguska-type collisions may have occurred at ~500 AD, a time which tallies with bizarre phenomena that seem to have accompanied the end of the Roman Empire. Gibbon [48] refers to a 'fever of the Earth that raged with uncommon violence during the reign of Justinian (AD 527-565)...Each year is marked by the repetition of Earthquakes, of such duration and severity that Constantinople has been shaken for above forty days...'. As the Roman Empire collapsed, so did that of the Guptas in India, which it seems was torn asunder by the revolt of the Huns. Further, W.M. Smart refers to Islamic text at a similar time which states: 'In the year 599 on the last day of Moharrem, stars shot hither and thither and flew against each other like a swarm of locusts; people were thrown into consternation and made supplication to the Most High.'

Purely scientific evidence from dendrochronology has also been adduced to support the idea of an externally caused ecodisaster occurring at around 540 AD [50]. From studies of tree ring thicknesses corresponding to the

early decades of the 6th century AD, it has been found that a major dip in the Earth's temperature occurred over the entire period AD 536–546. The competing idea that a volcanic eruption was responsible for a dust shroud that lowered the mean temperature and reduced tree growth for a decade or more does not accord with the lack of an acid signal in Greenland ice-drills encompassing the same age. Furthermore, volcanic dust is known to settle in a couple of years at the outset, so cannot easily explain the protracted episode of cooling that has been found. We note that contemporary literature also concurs with dendrochronological data. It has been stated that 'the sun was dark and its darkness lasted eighteen months...the sun appears to have lost its wonted light and appears of a bluish colour...fruits did not ripen...cold and drought finally succeeded in killing off the crops in Italy and Mesopotamia and led to terrible famine in the following years.' The scene was surely set for widespread mayhem and the collapse of empires that followed.

Acknowledgements

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Table 1. Periodicity in the terrestrial record.

Left–hand column: peaks from a power spectrum analysis of all global events (excluding those more recent than 8 Myr BP). *Center column:* individual peaks in the mass extinction record. *Right–hand column:* peaks from a PSA of all global geological events (excluding ≤ 8 Myr BP).

'All data' peaks	Extinction peaks	Geological peaks
–	1.6	2.0
11.9	11.2	10.3
37.8	36.6	36.6
63.7	66.0	62.9
88.8	91.0	89.3
115.5	113.0	115.6
141.4	144.0	141.9
167.3	176.0	168.2
193.2	193.0	194.5
219.0	216.0	220.9
245.0	245.0	247.2

Figure captions

Fig. 1. *Top:* Percentage of marine genera extinctions from mid–Permian to Recent, according to Raup & Sepkoski [1]. Excluding the recent surge of activity attributed to Gould's Belt disturbance, the best–fit periodicity is $P = 12.2 + 25.9n$, $n = 0, 1, 2, ..$ (P in millions of years BP).
Bottom: Major geological events [12], plotted with exponential smoothing within a 4 million year window. Best–fit periodicity, excluding recent activity, of $P = 10.3 + 26.3n$, $n = 0, 1, 2, ...$ is marked by vertical dashes.

Fig. 2. Stability of the combined extinction and geological data against progressive truncation of the data, T_{max} the upper limit (the recent out–of–phase surge is again excluded). *Left:* Variation of period P and phase ϕ. *Right:* Behaviour of typical synthetic data simulating the real data (with regard to trend and edge effects) but with each datum perturbed randomly in the range ± 24 Myr. Trials with such data favour periodicity over chance at a confidence level $\sim 1 - 10^{-3}$.

Fig. 3. *Top:* Modulation of Oort cloud flux into the planetary system caused by numerous mini–showers, generated by encounters with passing dark bodies. In this case the assumed perturbers are assumed to be Population I black dwarves which penetrate the dense inner core of the Oort cloud, while the solar orbit is taken to have vertical amplitude 80 parsec in the Galactic disc. The adiabatic tide due to the cumulative effect of remote perturbers yields a similar flux amplitude. *Bottom:* As above but with 4 million year smoothing corresponding roughly to the diffusion time of comets within the planetary system [13].

Fig. 4. Representation of Gould's Belt and related gas, adapted from Olano, C.A., *Astron. Astrophys.* **112**, 95 (1982). The system is expanding and comprises an outer ring of young stars which has detached from an inner gas ring. Its mass $M \gtrsim 10^6 M_\odot$, and the current distance to its center, 166 pc (Olano) or 80±40 pc (Comeron, F. & Torra, J., *Astron. Astrophys.* **241**, 57 (1990)), are critical in respect of the inferred relative amplitudes of the impulsive and steady components of the galacto-terrestrial cycle. The solar system appears to have passed through the rim of the Belt $\lesssim 10$ Myr BP.

Fig. 5. The ratio of radiation pressure to gravity for spherical particles near the Sun. The curve G refers to graphite; I refers to iron; D100, D60, D40 refer to a sequence of non-porous grains, 60% volume-filled porous grains and 40% volume-filled porous grains respectively. The dotted and dashed lines show critical P/G values for retention in bound orbits.

Fig. 6. The characteristic Poynting-Robertson lifetimes for particles in heliocentric orbit at 1 AU. The symbols marking the curves refer to the same cases as in Figure 5.

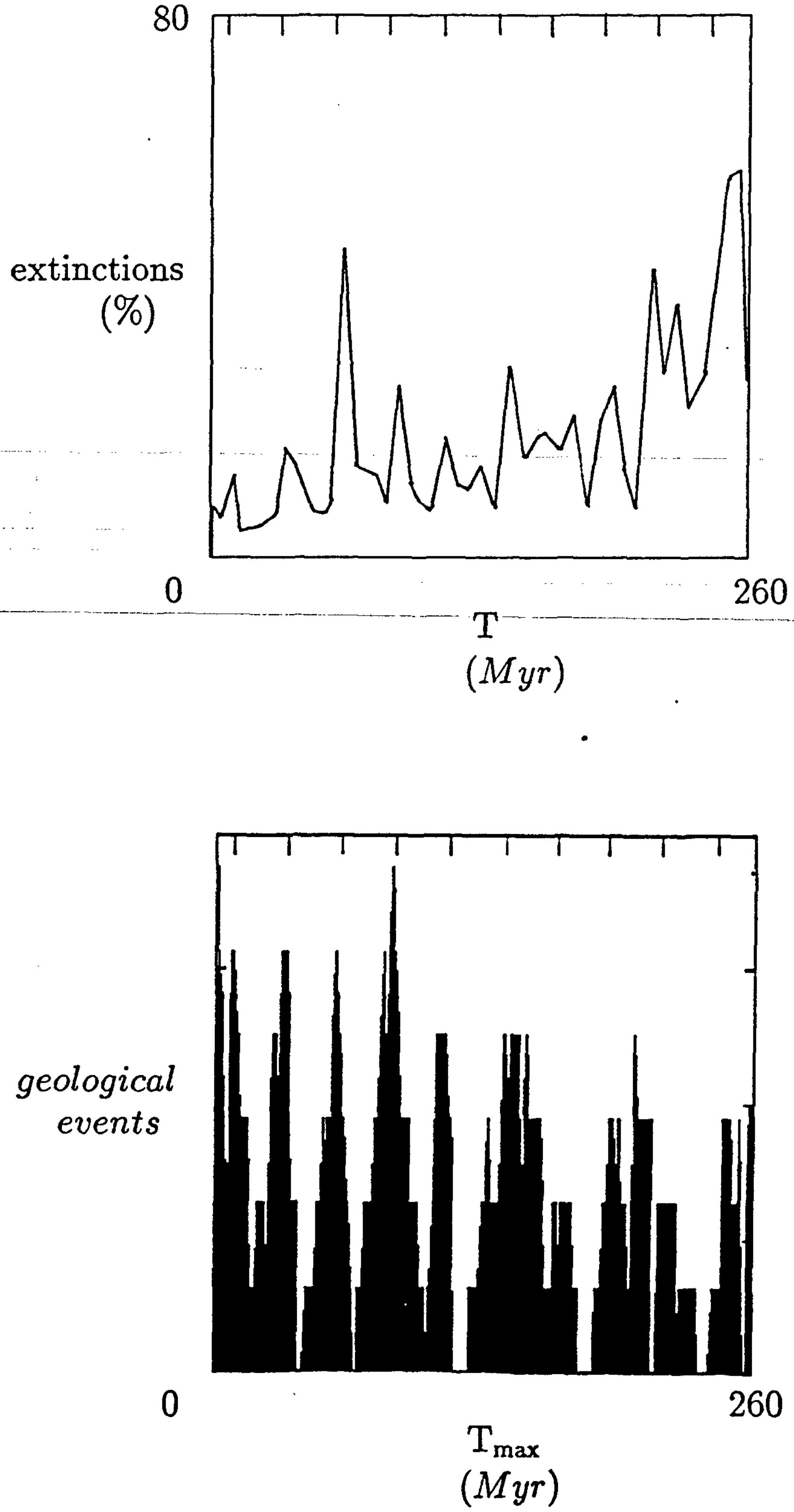


Fig. 1

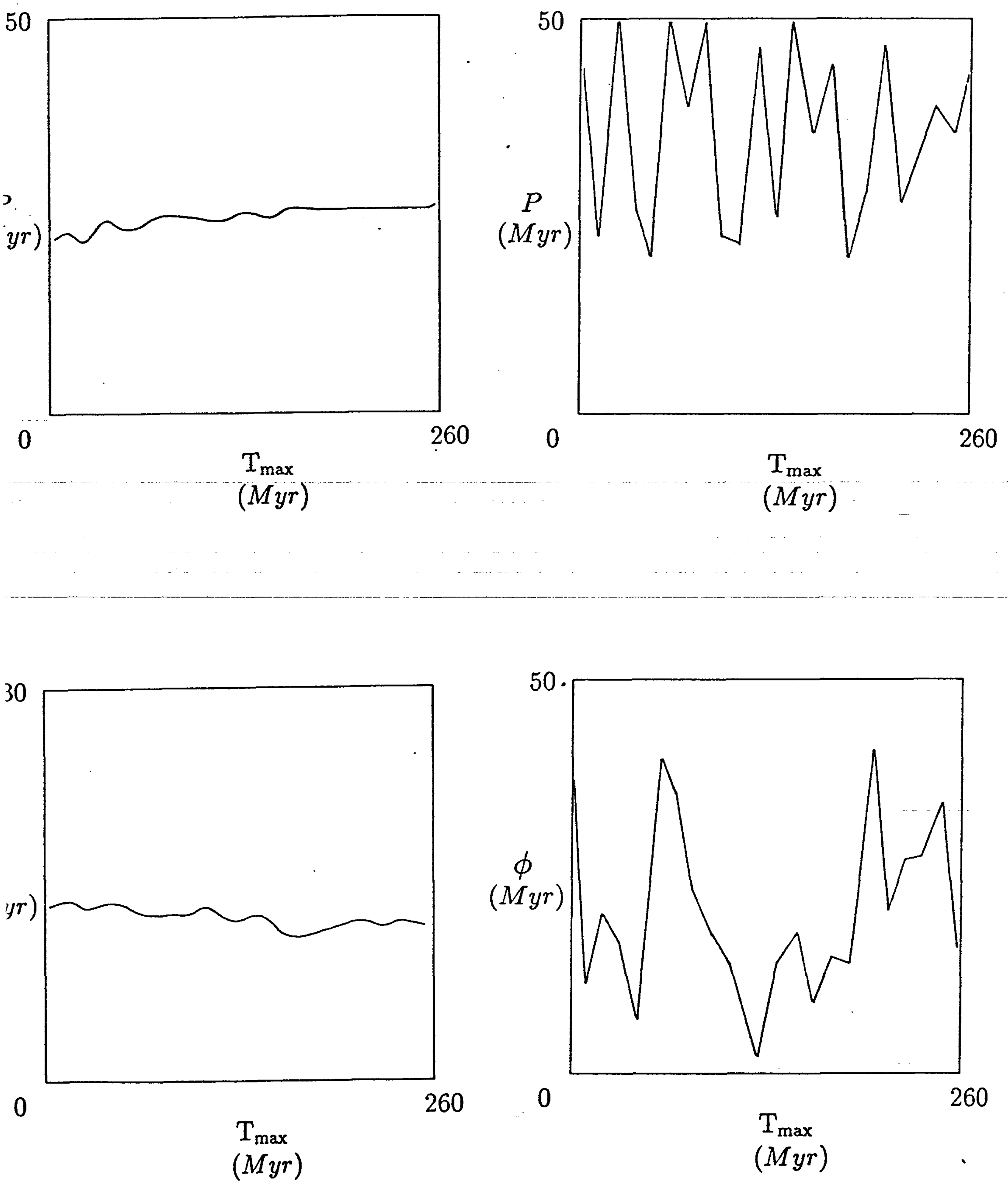

50
yr)
0
260
T_max
(Myr)
50
P
(Myr)
0
260
T_max
(Myr)
30
yr)
0
260
T_max
(Myr)
50
ϕ
(Myr)
0
260
T_max
(Myr)

Fig. 2

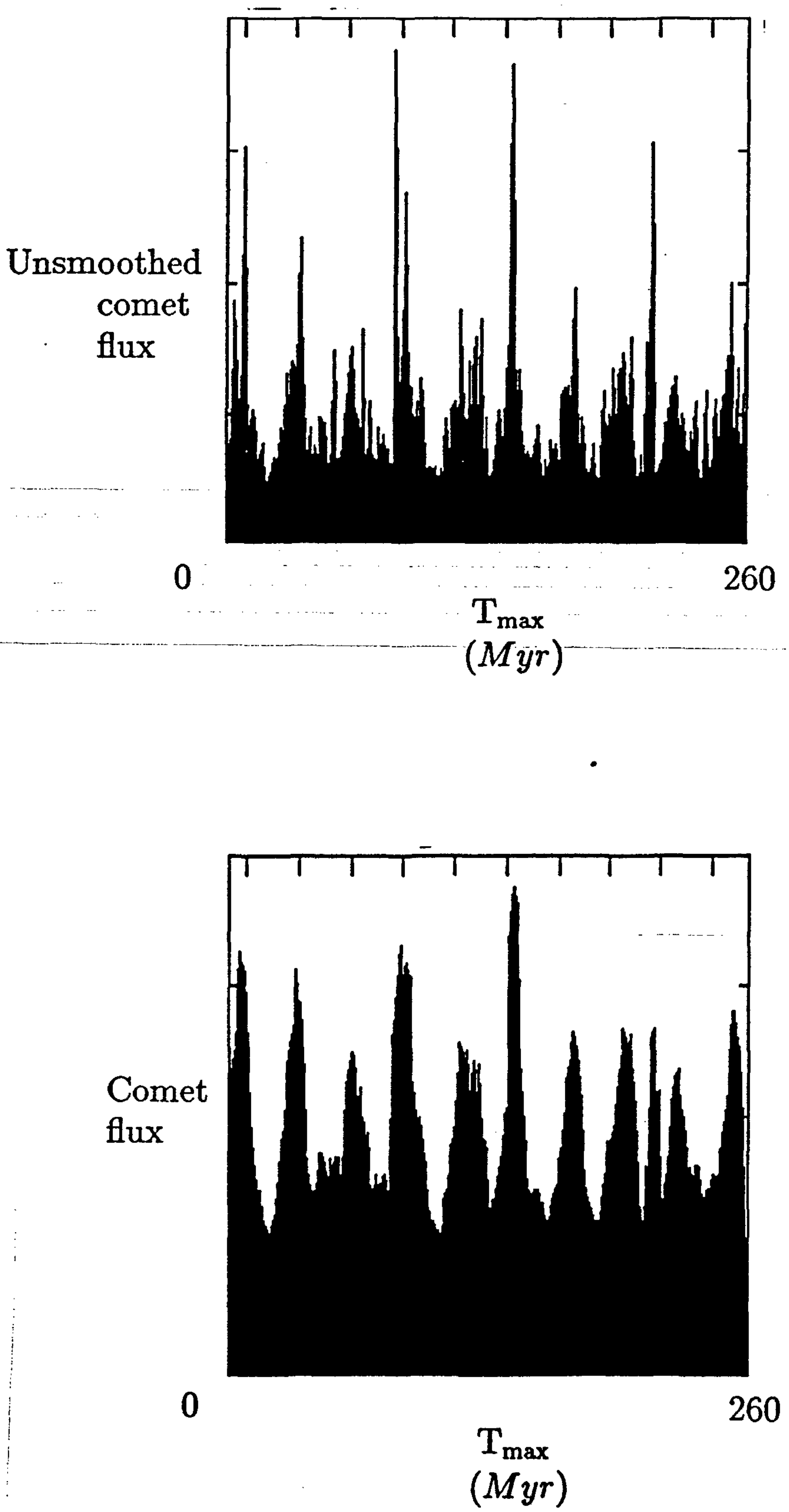

Unsmoothed comet flux
0
260
T_{max} (Myr)
Comet flux
0
260
T_{max} (Myr)

Fig. 3

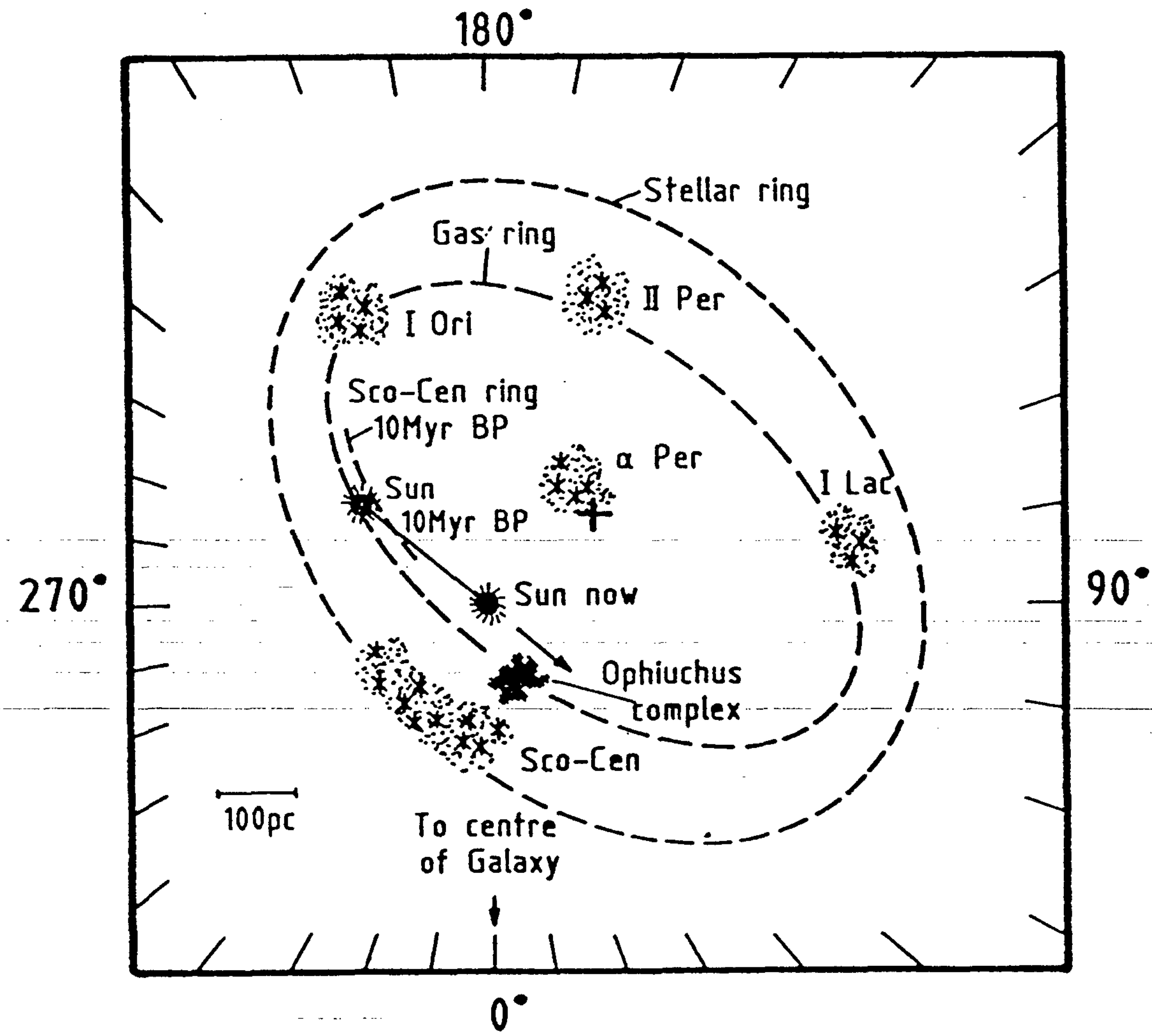

180°
Stellar ring
Gas ring
I Ori
II Per
Sco-Cen ring
10Myr BP
α Per
Sun
10Myr BP
I Lac
270°
90°
Sun now
Ophiuchus
complex
Sco-Cen
100pc
To centre
of Galaxy
0°

Fig. 4

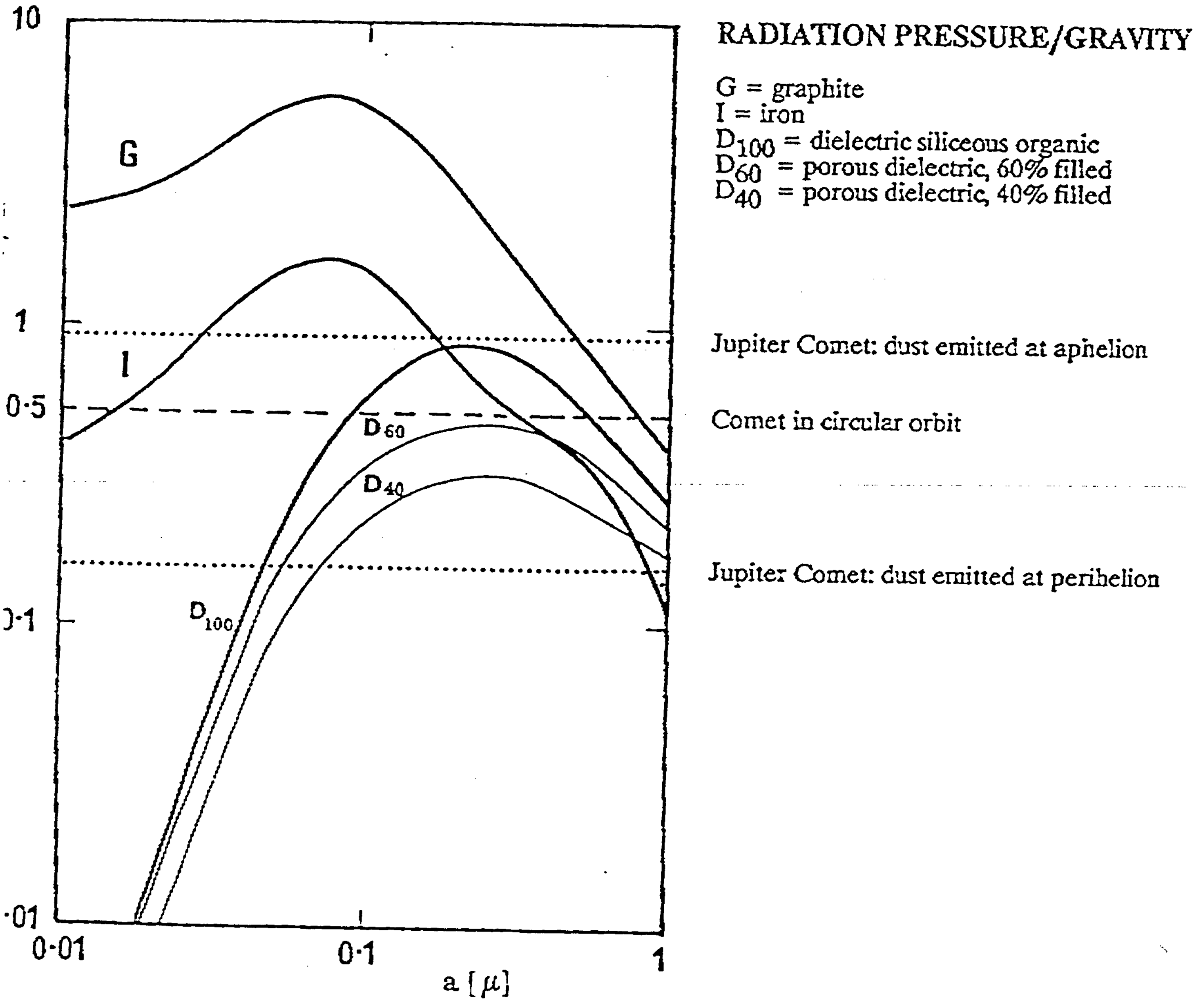
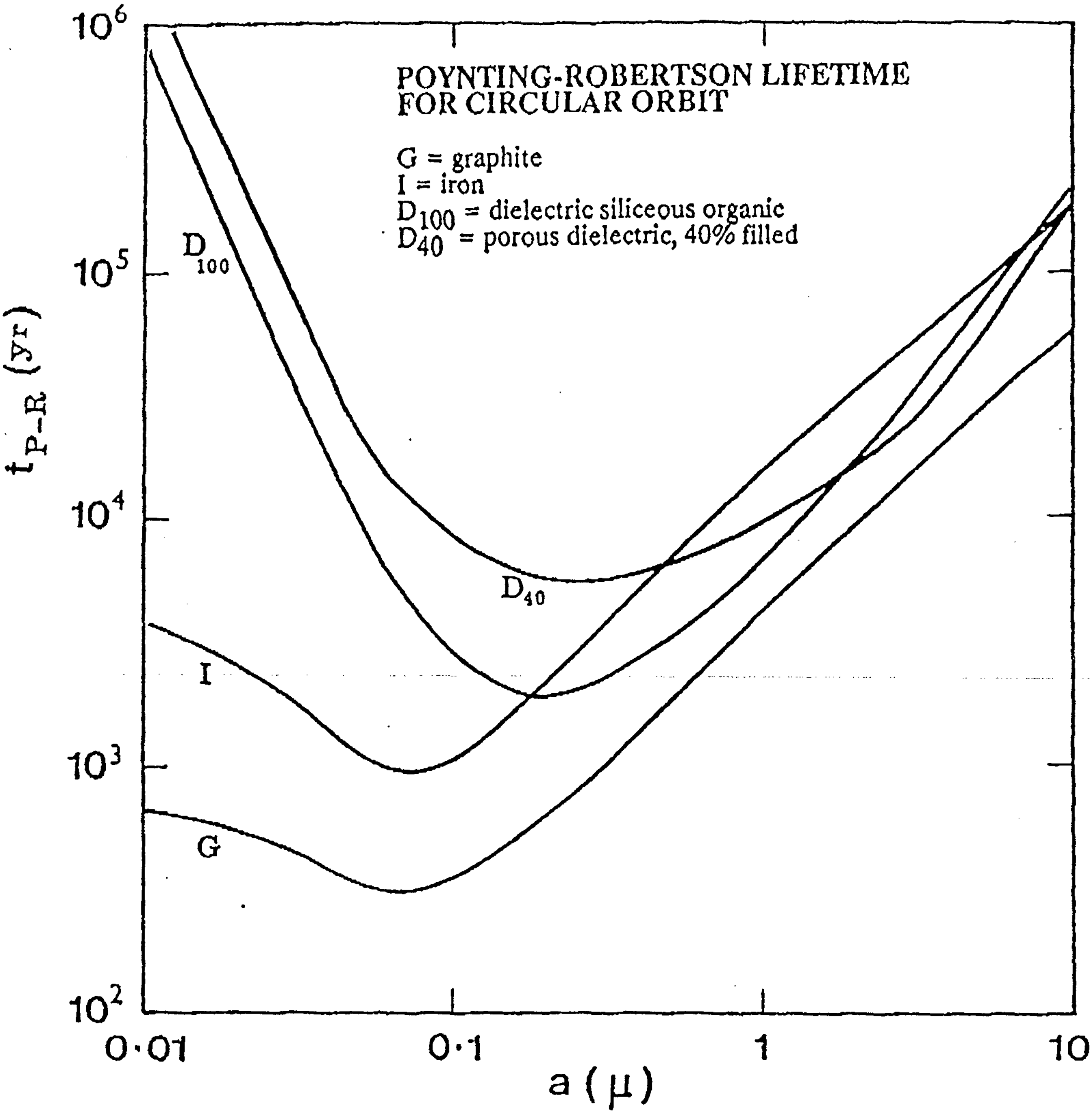

10
1
0·5
0·1
·01
0·01
0·1
1
a [μ]
G
I
D 60
D 40
D 100
RADIATION PRESSURE/GRAVITY
G = graphite
I = iron
D100 = dielectric siliceous organic
D60 = porous dielectric, 60% filled
D40 = porous dielectric, 40% filled
Jupiter Comet: dust emitted at aphelion
Comet in circular orbit
Jupiter Comet: dust emitted at perihelion

Fig. 5



POYNTING-ROBERTSON LIFETIME FOR CIRCULAR ORBIT
G = graphite
I = iron
D100 = dielectric siliceous organic
D40 = porous dielectric, 40% filled
D100
D40
I
G
10^6
10^5
10^4
10^3
10^2
t P-R (yr)
0·01
0·1
1
10
a (μ)

Fig. 6

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Appendix A: the nature of the cometary hazard

The celestial hazard ostensibly feared most by our ancestors during enhancements of the global fireball flux was a sustained bombardment by larger cometary debris. Included here is the Prologue of "The Cosmic Winter" by Victor Clube and Bill Napier (Basil Blackwell), Oxford 1990), conceived before the Cold War came to an end and providing a sketch of the feared conditions translated to a contemporary environment. This sketch anticipated the tidal break-up of Comet P/Shoemaker-Levy 9 and its subsequent bombardment of Jupiter by four and six years respectively.

WE DEDICATE THIS BOOK TO

FRANCIS, TRISTAN, MARIE-ANNE AND BENEDICT

AND TO

BRUCE AND AILSA

THE COSMIC WINTER

VICTOR CLUBE
AND
BILL NAPIER

Basil Blackwell

The priests of the mysteries tell us what they have been taught by the gods or mighty daemons, whereas the astronomers make plausible hypotheses from the harmony that they observe in the visible spheres.

Julianus, Emperor of Rome, AD 361-363

Prologue

It is 7.17 am, Eastern Standard Time, on the thirtieth of June 1994. Suddenly the power fails.

The basement centre of the Defense Communication Operations Unit adjoining the White House is plunged into darkness, and only the distant rumble of early morning traffic reminds the duty officer that another day has already begun. There have been power failures before, however, and there is no hint of impending crisis.

Almost immediately, an automatic switch brings in the emergency supply. But now the duty officer observes that something is wrong. Telephone links to the outside world have gone. These include the open links, via commercial cables, to NORAD's bunker a thousand feet under Cheyenne Peak in Colorado, and to the Offutt command post near Omaha.

Within seconds it is ascertained that neither the President nor Vice-President, both of whom are out of town, can be contacted: radio communications are blacked out, on all frequencies. Further, because of the telephone failure, none of the Presidential stand-ins scattered around town and country can be expected to call in to give their exact locations, as they would normally if there were a recognized national emergency. However, the Secretary of Defense, third in the chain of command, is at breakfast somewhere in the White House.

It has taken 45 seconds to confirm the general breakdown of communications; it takes another 45 seconds to locate the Secretary of Defense and inform him of the problem; and it is another 90 seconds before the Secretary finds himself in the cramped underground Situation Room along with his advisors. He is aware that the travel time of a missile from a hostile submarine off the Atlantic coast to Washington is just over fifteen minutes; three of these minutes have gone.

Emergency procedures for transferring authority are now in hand

and the Secretary of Defense becomes in effect the new President. The 'gold codes', which would enable him to initiate a nuclear response, are placed before him. The black SIOP books with their theoretical scenarios are produced. The 'Mystic' and 'Nationwide' communication systems are successfully activated utilizing deeply buried, protected cables. He now has control of the National Command Authority, the channel of communication for execution of a nuclear strike; and another two minutes have gone.

The underground cables to Cheyenne, Offutt and other SAC bases are now open with secure links to the radar lines covering the northern approaches. None of them – Dew Line, the 55th Parallel or Pine Tree – is functioning properly, however; their screens are strongly upset with many spurious signals: there seem to be huge scattering modes in the ionosphere. Satellite communication with military forces abroad is impaired. No information is coming in from the big synchronous DSP satellites over South America, the central Pacific or the Indian Ocean; nothing is arriving from the relay stations near Aurora in Colorado or Pine Gap in Australia. And the 'hot line' is dead. On the other hand in the minutes before the confusion they had reported no anomalous infrared emissions and hence no evidence of heat from the exhausts of rising missiles. At the moment all that can be said is that there is a very unusual atmospheric disturbance, that telephone lines are dead and that there are widespread power failures. The disturbed atmosphere might just be some strange effect due to sunspots or the like, but the telephone and power failures are ominous. On such a scale, the only plausible explanation is an electromagnetic pulse caused by nuclear fireballs.

Eight minutes into the emergency – if it is an emergency – the Secretary issues a number of precautionary orders. His deputy is ordered upstairs to await the arrival of a helicopter from Quantico Marine Corps base about 30 miles away. This will transport the deputy to the waiting 'Nightwatch', a Boeing 747 which functions as an airborne command post. Another helicopter is despatched to retrieve the President. A 'flash alert' is sent to Hawaii, to get a second command post aloft, but the message goes unacknowledged. SAC missile silos and bomber bases are put on full alert.

Nine minutes on, information begins to flood in from sensors and antennae in orbit, at sea and scattered round the Earth. Much of it is reassuring: there are no patterns of activity on land, sea or air consistent with hostile intentions, no evacuations of barracks or the

like are in progress. But now something deeply disturbing is coming in from one of the DSP satellites. A television screen shows a brilliant patch over south-east Nevada, bright enough to saturate the lead sulphide cells in the satellite. Intense heat is radiating from an area of about ten thousand square kilometres. Distant ground sensors are reporting large tremors emanating from the same area – unnecessarily, as the Situation Room has begun to sway and vibrate, and loud rumblings are coming up from deep under the ground. Then, from Offutt, comes devastating news. Air Force pilots are reporting a huge explosion in the desert area close to Boulder City. The city itself has gone, reduced to rubble. Las Vegas and other towns within 100 miles are enveloped in huge firestorms. The Hoover Dam has disintegrated. A column of dust and rubble has been sucked up to great altitude and a mushroom cloud is spreading outwards. Huge amounts of smoke are blanketing the state of Arizona and spreading into New Mexico and Mexico itself. The Secretary and his advisors can see it all on their television screens.

The Secretary now has a maximum of five minutes in which to discuss and evaluate the information, make any decisions and implement them. He is informed that the damage corresponds to explosions amounting to at least twenty megatons, and must have been caused by more than one bomb. The possibility of accidental detonations is quickly ruled out, because of its technical improbability and the magnitude of the explosion. Further, he is told that both ground and air bursts must have been involved to disrupt both cable and ionospheric communications. The conclusion seems unavoidable that for some reason the Soviets have targeted bombs on to American territory having somehow circumvented military radars. Perhaps armed satellites with low radar cross-section have suddenly been diverted downwards; or perhaps submarine-launched cruise missiles have been fired; or perhaps bombs had already been smuggled into the area. But why? The desert is a bizarre choice of target, Boulder, Las Vegas and the Hoover Dam of low strategic value. No sense can be made of the attack. Perhaps, it is suggested, they were chosen *because* they have little value. The attack may be a prelude to some major military adventure and may be a warning, a 'keep out' notice pitched at a level low enough that the risks of nuclear response are not justified and yet high enough to demonstrate deadly earnest. Or, the impacts may be intended to disrupt radar and communications for reasons which can only be guessed at.

Whatever the merits of such speculations, the Secretary cannot responsibly rule out the possibility that further bombs may follow, completely jamming command and control over nuclear weapons, or even that Washington is an imminent target whose destruction might for example be awaiting only the positioning of armed satellites, already in orbit, over the city, or the arrival of cruise missiles. Twelve minutes into the emergency, the Secretary's deputy is still on the White House lawn waiting for a helicopter, there is no communication with the President and the only information still coming in confirms that towns over several thousand square miles have been destroyed in nuclear blasts. He has no time left and must come to an immediate decision.

He could initiate the dreaded 'Major Attack Option'. This is quickly ruled out because it is beyond reason, leading only to mutual annihilation. He could choose to do nothing. But it is pointed out that in the present situation paralysis could also lead to holocaust. Whether the National Command Authority is 'decapitated' in the next few minutes depends on whether further missiles are about to land. If they are, then all control over the counter-strike force may be lost and, with bombs falling on the USA, a full-scale attack on the Soviet Union will, following standing instructions, be unleashed by individual submarine commanders, and by the one-star generals aboard their Cover All airborne command posts. It is therefore vital to forestall any further nuclear attacks by calling the bluff, that is by retaliating at a similar level. All the options are dangerous. The least dangerous is an immediate 'controlled response'.

The discussions are interrupted by confused reports of a storm of missiles, a cataract of fire pouring in over the states of the western seaboard and Canada. But the reports go unconfirmed; again, communications are failing over the whole of the United States.

It is 7.30 am, Eastern Standard Time, on the thirtieth of June. In the revamped over-the-horizon radar base near Gomel in Byelo-Russia officers are horrified to see, through the confusion of the still-disturbed ionosphere, a dozen missile tracks appearing on their screens. Peacekeepers are rising over the plains of Kansas. . . .

Even as they look, however, another unheralded missile is encountering the atmosphere high over the Bernese Oberland. Coming in at sixty thousand miles an hour, a hundred kilometres above Interlaken, the missile is gathering around itself a narrow skin of compressed air whose temperature surges up to about half a million degrees. Waves ripple within the hot air-turned-plasma; atoms, scattering off the waves, reach huge speeds, collide violently, and are stripped to their nuclei; electrons, torn from the atoms, accelerate violently and radiate fiercely at all wavelengths. For the most part this fierce emission is invisible, hard ultraviolet light or soft X-rays, and the atmosphere absorbs these at altitude, 50 to 90 kilometres up. Only a tiny fraction of the radiation reaches the ground as visible light. Even so, Europe is lit up as if with a flashbulb: survivors from Ireland to Austria and from Denmark to Italy later describe 'a bluish white light, too bright for the naked eye', or 'a fire brighter than the Sun', or 'a thunderbolt . . . blinding in its intensity'. Approaching from the south east, the missile passes on a long, shallow trajectory, throwing moving shadows over the Jungfrau, Berne and Basle. It crosses the sky in a few seconds, leaving a wake of hot, luminous debris and air surrounded by a rapidly expanding red trail. Ten seconds after its first encounter with the atmosphere, the missile has penetrated the ionosphere, passed through the stratosphere and is moving rapidly into the lower atmosphere.

Here at an altitude between 10 and 15 kilometres, the missile hits significantly denser air and suddenly disintegrates. It never reaches the ground therefore and instead unloads its stored-up power, 200 megatons of impact energy, into the air over Louvain, a medium-sized town in central Belgium. The missile vaporizes in a third of a second. It is now, momentarily, an incandescent cylinder a few kilometres long and a few hundred metres across. The temperature within the cylinder is over 100,000° C. The pressure for an instant reaches some tens of thousands of tons per square inch; the missile blows up into a ball of fire radiating X-rays of huge intensity. These are absorbed within a few metres by the surrounding air; but, in doing so, the envelope of atmospheric gas acquires their energy. Simultaneously, hot, compressed material is thrusting rapidly outwards from the point of disintegration and snowploughing the air ahead of it. A blast wave develops; the fireball expands. From the first trace of incandescent tail high over Interlaken, to the beginnings of the fireball over Louvain, less than eleven seconds have elapsed.

When the fireball has reached about four miles in diameter the shock wave breaks away and races ahead of it. The corresponding blast brings a wind speed of over a thousand miles an hour. Survival at this distance is impossible; Louvain, directly under the fireball,

disappears in less than a second. The fireball meanwhile inflates and soars rapidly upwards for several kilometres until, in the stratosphere, it flattens out and takes the classical mushroom shape. The cloud is seen from Copenhagen to Florence, from Edinburgh to Budapest. And over the whole of Europe, the ground shakes and buildings sway dangerously. Trains are derailed in southern England and beneath the Channel. The mushroom cloud is quickly broken up by jet streams at about 60 kilometres altitude and is subsequently dispersed around the globe.

Within 25 kilometres of Louvain, all buildings are reduced to rubble. A few girder bridges survive due to accidental cancellation of pressure waves from above and below. The shock wave reaches Brussels to the west and Liege to the east. The buildings within these cities collapse, domino-like, as the wave sweeps through; and all traces of roads are immediately erased by rubble. Beyond 25 kilometres, some structures survive, although few houses remain intact. Throughout Antwerp, for example, about 50 kilometres from ground zero, roofs are stripped bare of tiles and window frames and doors are blown in. Beyond this the damage becomes lighter: about 100 kilometres to the north the blast, sweeping through Eindhoven, blows tiles off roofs and shatters windows.

People out of doors and 25 kilometres from Louvain are hurled about 10 metres and are usually killed. Flying glass, though, is the greatest hazard. Shopping precincts and office complexes within 50 kilometres find themselves swept without warning by lethal blizzards of flying glass. Indeed, shards of glass account for most of the loss of life in these areas. Even 100 kilometres from the epicentre of the explosion, the blast is still strong enough to flatten forests.

Nuclear reactors within reach of the ground tremors and air waves are damaged, their coolant pipes snapped and containment vessels cracked. Some begin the process of meltdown. Already, swathes of radioactive debris are pouring into the atmosphere, mingling with the dense chemical smog, drifting into Germany, and destined for Poland and Scandinavia.

Immense destruction is caused by fire as well as blast. Serious flash burns from the thermal pulse of the fireball are sustained over an area of several thousand square kilometres, and virtually all exposed individuals within about 50 kilometres of ground zero receive third degree burns (charred skin) requiring labour-intensive hospital treatment, but in the hours and days following the impact it

is impossible for medical services from outside to reach, let alone cope with, the seriously burned, and many of the injured die untreated from shock within twelve hours.

The intense heat from the rising fireball sets off fires at a range of 70 kilometres or more. Fanned by the updraft of air sucked in behind the rising ball, these merge into a mass fire, a single all-consuming conflagration. Such fire services as have survived are immobilized in a sea of debris, deprived of water and overwhelmed by the extent of the raging fire. The Sun eventually sets, but Europe is already dark, only the light from raging fires penetrates the smoke.

Sixteen hours after the event the Sun rises again, but it shines down only on a dense, choking smog created by blazing cities and petrochemical complexes. Aerial survey is impossible. Within a circle of radius 50 kilometres, the dead greatly outnumber the living. Even without the mass fire which is still blazing, penetration of the area is impossible as roads are strewn by debris and wrecked vehicles. It will be several days before the fires burn themselves out and the smog disperses enough to reveal the flattened cities and towns, villages and farms. Belgium, it will turn out, has been obliterated. And several weeks would need to pass before French, German and Dutch forces have the capacity to clear the roads, shelter the living and bury the dead. Belgium, however, will wait in vain . . .

For the Earth has encountered a cosmic swarm. Twelve hours later, the death-dealing fusillade is peppering the other side of the globe. Indeed, the bombardment continues for nearly a night and day, the planet rotating all the while, first presenting one face, then the other, until eventually it emerges on the far side of the swarm. Compared with the fireball over Hiroshima at the end of the Second World War, that over Boulder was a thousand times greater whilst that over Louvain was ten times bigger again, but they are just two of the several hundred pieces of grape-shot that meet the Earth, and they are trivial compared with the larger pieces of ordnance in train. These rarer missiles are each capable of unloading as much energy as would be unleashed in a major nuclear war, and in their case the atmosphere provides relatively little protection. Thus unlike their smaller counterparts, these larger bodies get through to the surface of the Earth, an ocean impact generating a tsunami, a land impact generating a small crater. There is another difference: each huge fireball is now too energetic to be properly contained by the

atmosphere. As before, it ascends, laden with dust, but now it breaks through generating a vacuum in its wake which is filled by a vast stream of air. Thus, on the ground, once the initial blast has swept past, there is a counterflowing hurricane, itself sweeping up dust thrown up by the impact, and blowing it upwards after the rapidly receding fireball. Within minutes the fireball has reached an altitude of several hundred kilometres, in the high stratosphere. Here it stabilizes, and the dust begins to spill outwards over the top of the atmosphere.

Closer to the ground, the intense heat of impact from one large fireball has generated hundreds of fires over an area about the size of France. Essentially everything combustible along the line of sight of the rising fireball has caught fire. Loss of life over this area, already massive from the prompt effects of blast and heat, becomes almost complete when these fires merge into a single, all-consuming conflagration. About fifty million tons of smoke pour upwards, in dense plumes rising 10 kilometres into the atmosphere.

Within a few days, the wildfires are almost global in extent. Tens of millions of tons of fine dust lofted into the stratosphere, and a comparable amount of smoke in the lower atmosphere, have spread over the northern hemisphere and are beginning to cross into the southern one. At ground level, sunlight is blocked from reaching the ground, and all activity takes place in a black, choking smog. There is no question of mounting any rescue operation to save the devastated areas: the damage is so widespread that communications around the globe have now effectively ceased to exist; individual regions are virtually isolated; devastated populations are thrown back on their own resources; dozens of cities are reduced to smouldering rubble; river pollution is rife; and forests throughout the world are ablaze. Life as we know it is drawing to a close.

The cosmic encounter is over. Our planet has finally emerged from the swarm. Both continue, of course, along their predestined paths, the swarm merely a few missiles less, the Earth now charred and encased in a lingering veil of dust and smoke. With the destruction of cities and urban areas, the infrastructure of civilization has already gone; with the loss of sunlight, continental land temperatures have already plummeted to those of a Siberian winter; thick ice covers rivers and lakes; storms of unprecedented intensity rage along the continental margins; with animal and plant life devastated, farming and agriculture have already collapsed. Soon, the disrupted

weather patterns will cause the continental land masses to be blanketed in a thick covering of snow.

After several months, the Sun begins to be seen through a hazy sky. When, eventually, the dust clears, the land masses of the northern hemisphere are covered in a snowfield which, reflecting sunlight back into space, has become permanent. The snowfield is added to each year, centimetres at a time. A thousand years on, North America and Europe are covered in ice sheets half a mile thick and the ocean level has dropped by about fifty metres. The Earth is locked into a new ice age. Mankind has survived, but the human population has crashed and society has dissolved into hungry marauding bands. A new ecological balance is being worked out on the blasted landscape: indeed the struggle for survival has only just begun. . . .

What is to be made of a future that turns out this way? First and foremost, of course, it must be established whether a true prognosis has been given; and if not in exact detail, at least in general terms. Next, should the future be as bleak as it appears, perhaps it must be recognized that very little can at present be done to remove personal risk except by fostering such stoical reserves as are necessary to face the slings and arrows of outrageous fortune. But what of culture, society and civilization? For these also appear to be at risk from the course of events we describe. Does one perhaps comfort oneself with the thought that not all would be lost since it is a reasonable expectation that some archaeologist, thousands of years hence, is bound to recover the essential achievements of our civilization, preserved in London, say, beneath a silted-up Thames? Alternatively, does one perhaps take strength from the known capabilities of the human race, on the basis, for example, that an engineer or physicist, also thousands of years hence, is bound once again to invent the internal combustion engine? Or does one picture a world peopled by then with a race of frankenstein monsters, indifferent to all but themselves? That is, should one envisage a swarm in the sky which is also the bearer of a cosmic imprint capable of affecting cellular life and marking out a new small branch in the evolutionary tree? Is civilization, indeed, simply a cul-de-sac, a diversion before a new dominant species – 'homo unsapiens' we might suppose – inherits the earth?

Science has no answer to these questions. Indeed, those who

might be expected to contribute to the answer are not at the moment interested. The environment in which our planet moves is supposed to be empty, and to pose little threat. We shall show, however, that the reality is different; that an unrecognized hazard is out there; and that at a stroke, civilization could be plunged into a new Dark Age.

The future shocks described herein are the logical consequence of new discoveries which have been emerging over the past few years. Some preliminary findings were described in an earlier book, *The Cosmic Serpent*, but the analysis has since been greatly extended, and we did not there deal with the implications for the future. That omission is here rectified. As we anticipated, some 'authorities' reacted to the book with outrage, and indeed the reader should be warned: much of what he may have regarded as established truth will in these pages also turn a somersault.

In June 793, 'fierce foreboding omens came over the land and wretchedly terrified the people', signs that are said to have been followed by great famine. On 25 June 1178, the Moon, more or less in line with the Earth, was apparently struck by a missile whose energy was ten times that of the combined nuclear arsenals of the world. On 30 June 1908, an object from space exploded above a remote area of Siberia with the energy of a large hydrogen bomb. More recently, during five days in late June 1975, an unexpected swarm of boulders the size of motor cars struck the Moon at a speed of 67,000 miles an hour. And then again, on 30 June 1994, there came an unheralded explosion with the strength of a 20-megaton bomb....

Why late June? What is the nature of these events? And what is the actual threat they pose for mankind? Such are the questions we address in this book. For within these last few years, it has been found that there is a great swarm of cosmic debris circulating in a potentially dangerous orbit, exactly intersecting the Earth's orbit in June (and November) every few thousand years. More surprisingly, perhaps, it has been found that the evidence for these facts was in the past deliberately concealed. When the orbits exactly intersect however, there is a greatly increased chance of penetrating the core of the swarm, a correspondingly enhanced flow of fireballs reaching the Earth, and a greatly raised perception that the end of the world is nigh. This perception is liable to arise at other times as well, whenever fresh debris is formed, but deep penetrations occurred during the fourth millennium BC, again during the first millennium BC, taking in at their close the time of Christ, and will likely take place yet again during the millennium to come.

Christian religion began appropriately enough therefore, with an apocalyptic vision of the past, but in the aftermath of the last deep penetrations, once the apparent danger had passed, truth was converted to mythology in the hands of a revisionist church and such prior knowledge of the swarm as existed, which now comes to us through the works of Plato and others, was later systematically suppressed. Subsequently the Christian vision of a permanent peace on Earth was by no means universally accepted, and it was to undergo several stages of 'enlightenment' before it culminated with our present secular version of history, to which science itself subscribes, perceiving little or no danger from the sky. The lack of danger is an illusion however, and the long arm of an early Christian delusion still has its effect. *The Cosmic Winter*, then, is a kaleidoscope of history and science, reviving the basis of an old and largely misunderstood pagan view of the world.

The idea of a terrible sanction hanging over mankind is not, of course, new. Armageddon has been widely feared in the past and it was a common belief that it would arrive with the present millennium. During the last thousand years, moreover, it has usually been the reforming church that revived the fear. But such ideas, whenever they have arisen, have always met with fierce opposition. Sometimes the proponents of such ideas escape to new found lands where in due course they meet opposition of a homegrown kind. In the United States for example, despite freedom of speech, old traditions of cosmic catastrophe have recurred from time to time, even in the present century, only to be confronted by pavlovian outrage from authorities. That being the case, it is perhaps ironic that elections in the United States are generally held in November following the tradition of an ancient convocation of tribes at that time of the year, which probably had its roots in a real fear of world-end as the Earth coincided with the swarm.

In Europe the millennium was finally dispensed with when an official 'providential' view of the world was developed as a counter to ideas sustained during the Reformation.[1] Indeed to hold anything like a contrary view at this time became something of a heresy and those who were given to rabble-rousing for fear of the millennium were roundly condemned. To the extent that a cosmic winter and Armageddon have aspects in common, therefore, authoritarian

outrage is nothing new. More to the point perhaps, the way in which the British parliament handles its affairs seems to have its roots in the condemnation of the heresy.[2] Thus the mother of parliaments, once its present charge was assumed, began by turning against the founding sect known as Ranters. Ranters rose to prominence in the period immediately following the execution of the English king and the foundation of the Protectorate. But they are heard of very little these days and it is not commonly known that Ranters took their lead in 1649 from one Gerrard Winstanley who was moved by 'supernatural illuminations', along with many others, to anticipate the millennium.

In the event, the 'destroying angel' failed to materialize, the ranting parliamentarians came to look foolish and it was only a matter of time before the reins of power passed to others of a more sophisticated persuasion whose vision of the world embodied the kind of 'enlightenment' that has sustained western civilization ever since. Enlightenment, of course, builds on the providential view and treats the cosmos as a harmless backdrop to human affairs, a view of the world which Academe now often regards as its business to uphold and to which the counter-reformed Church and State are only too glad to subscribe. Indeed it appears that repeated cosmic stress – supernatural illuminations – have been deliberately programmed out of Christian theology and modern science, arguably the two most influential contributions of western civilization to the control and well-being of humanity.

As a result, we have now come to think of global catastrophe, whether through nuclear war, ozone holes, the greenhouse effect or whatever, as a prospect originating purely with ourselves; and because of this, because we are faced with 'authorities' who never look higher than the rooftops, the likely impact of the cosmos figures hardly at all in national plans. Indeed, even those who do look higher are mostly content simply to weave plausible hypotheses from the harmony they observe in the visible spheres, and eschew any reference to cosmic hazards in the process.

And if the overall climate of our globe should once again improve, as it is doing during this century, and has done every few centuries since the end of the last ice age, there may be only the dimmest perception of an approaching nadir. We may be unaware that the cosmos is simply delaying the next input of dusty debris, alarm, destruction and death. A great illusion of cosmic security thus

envelopes mankind, one that the 'establishment' of Church, State and Academe do nothing to disturb. Persistence in such an illusion will do nothing to alleviate the next Dark Age when it arrives. But it is easily shattered: one simply has to look at the sky.

The outrage, then, springs from a singularly myopic stance which may now place the human species a little higher than the ostrich, awaiting the fate of the dinosaur.